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BUREAU OF STANDARDS
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By P. D. Sale and A. F. Hedrick

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ABSTRACT

The principal factors influencing the heat insulation of fabrics are discussed. Apparatus is described and methods proposed for the measurement of this and other related properties of blankets, viz, permeability to air and water vapor. Standard test conditions are recommended simulating those to which fabrics are subjected in service. Data illustrative of the several tests made on new blankets, typical of the variety to be obtained in the trade, are presented. The heat-insulating value of blankets is correlated with thickness, weight, and density of the specimens. It is planned to supplement this paper by a following publication, Specifications for Constructing and Operating the Heat Transmission Apparatus, and later by a more thorough analysis of experimental data, only a part of which has been presented herein.

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I. INTRODUCTION

Of the various measurable qualities possessed by fabrics used for wear or for bodily comfort, such as clothing and blankets, one of the most important is their heat insulation under service conditions. The need of the Army for estimating the relative values of purchased fabrics has hastened the prosecution of plans already outlined for developing what is believed to be, from this standpoint, an adequate and feasible method for determining the relative heat-insulating values of such materials.

Fabrics as heat insulators belong to the class which possesses that property to a very appreciable extent at least, by virtue of the enmeshed air spaces, dry air being among the best insulators

if prevented from forming stream lines and thus transferring heat by convection. However, it is necessary to recognize that they transmit heat in part by conduction of the fibers themselves, in part by convection of the enmeshed air, in part by the passage of evaporated moisture from the body, and in part by radiation to which they are more or less transparent. To be adequate, therefore, a test should measure the rate of escape of heat in these combined ways from a warm body on the one side through the fabric to free air on the other side. The problem, dealing with heat transfer through fabrics, is one of heat transmission rather than heat conduction.

For the same fabric material the heat-insulating value varies with the number and size of the enmeshed air cavities and with the freedom of air communication between them. This is governed not only by the manufacturing process, but also by subsequent history in service. The air space varies with density and weave of the fabric and with each subsequent manufacturing operation, such as napping, fulling, etc., also with wear and laundering. Napping a fabric increases its thickness without changing its weight appreciably, and must, therefore, increase the number or the size of the air cavities, actually both. Laundering may have the opposite effect.

But, of two fabrics equally good as to heat insulation, that one is more desirable which is more permeable to air and water vapor, in that it facilitates ventilation and the escape of evaporated moisture. Along with thermal resistance, therefore, it is desirable to know the permeability of the fabric to both air and water vapor. Methods have been devised for measuring these qualities also.

Rood [1] has measured the heat flow through fabrics held between metal disks under slight pressure. These conditions do not permit evaluation of the escape of heat from the fabric into free air. Priestman [2] wrapped the samples of cloth around metal cylinders filled with hot water, and measured the rate of cooling of the water. Haven [3] wrapped specimens of fabric three layers deep around a copper pipe and weighted the free end to keep the specimen taut. An electric heater inside the pipe was maintained at a constant temperature and the power required to do

[1] E. S. Rood, "Thermal conductivi y of some wearing materials," Phys. Rev., 18, p. 356; 1921.

[2] Howard Priestman, "Heat retaining properties of woolen and worsted cloths," Textile Manufacturer, Jan. 15, 1922, p. 28.

[3] George B. Haven, Modern Methods of Testing Blankets for Heat Transmission, Bureau of Standards Miscellaneous Publication No. 19, p. 33.

this served to measure the rate of transmission of heat through the fabric. The outside temperature was also maintained constant. This was a distinct improvement over Priestman's method. Earlier investigators were Schumeister, Max Rubner, Wilhelm Nusselt, and A. Martens.

II. METHOD

As already stated, a method of test should, to be adequate, measure the rate of escape of heat from an object simulating the human body, through the specimen to free air on the other side, and this under variations met with in service. This requirement as to temperature conditions can be readily met, but to reproduce at the same time the factors introduced by perspiration from the body and outside air currents leads into undesirable complications. For this reason the test has been separated into three independent parts, namely: (1) The rate of escape of heat through the specimen under definite temperature conditions into still air having a prescribed humidity ("conditioned air"), (2) the rate of flow of conditioned air through the specimen under definite pressure difference and at a definite temperature, and (3) the rate of escape of saturated water vapor through the specimen from water maintained at 100° F. ("blood heat") to conditioned still air outside. While the test is thus simplified it necessitates for proper interpretation some arbitrary method of weighting the different factors, which, of course, is an admitted weakness.

1. HEAT TRANSMISSION

Assume a fabric of area A and uniform thickness L, having one face in contact at all parts with a plane heater maintained at a uniform temperature T, and the other face exposed to still air maintained at a temperature ΔT degrees centigrade below T. The presentation of the experimental results is simplified by comparing them with what would result in the case of simple conduction through an isotropic medium. Under such conditions the quantity of heat H transmitted per second through A, after steady conditions are reached, is simply proportional to ΔT. That is,

$$H = \frac{\Delta T}{R}$$

hence,

$$R = \frac{\Delta T}{H} \qquad (1)$$

where R is the thermal resistance. Experiment shows, however, that this R is made up of two independent parts, the one located at the boundary surfaces and the other distributed through the medium; that is, an abrupt drop in temperature is found at each surface and a gradual decrease through the transmitting medium. Calling the first ΔT_s and the latter ΔT_i, we have

$$R = \frac{\Delta T_s}{H} + \frac{\Delta T_i}{H}.$$

By introducing the thickness L in the second term we obtain a factor which specifies the thermal resistance of the medium. We may write,

$$R = R_s + \frac{\Delta T/L}{H} \cdot L$$

or

$$R = R_s + rL \qquad (2)$$

R_s being the combined thermal resistance at the two faces and r the thermal resistance per unit thickness of the medium, which, for short, we shall call the thermal resistivity of the medium.

With R_s constant, as is the case when no change is made in the material, the thermal resistance of a given body is a linear function of the thickness. By using different thicknesses the *thermal resistivity* of the material itself may thus be evaluated. As already stated, these deductions apply to conduction. They are not assumed a priori to hold under the conditions prevailing here.

2. HEAT TRANSMISSION APPARATUS

This follows the general principle of Haven's apparatus, using, however, a plane instead of a cylindrical heater. The prime features are an electric-heating grid covered with a copper plate for equalizing the temperature; the test piece of fabric, larger than this copper plate, laid over it under slight tension; thermocouples for measuring the temperatures of the plate and the surface of the fabric exposed to the free air; electrical apparatus and instruments for regulating and measuring the power supplied to the heater; all in a room in which the air is maintained at a definite temperature, definite humidity, and free from currents. To insure that all the measured heat flows normally through, and is dissipated from, a definite area of the fabric, equal-temperatured heat guards surround the edges and cover the back of the principal heater. The test is made with the specimen horizontal and the direction of heat flow upward. A cross-sectional diagram of this

heat transmission apparatus is given in Figure 1, and additional details in Figures 2 and 3. Refer to descriptive note below Figure 1 for meaning of reference letters.

In Figure 1 A is the central heating grid (31.42 by 31.42 cm), the power intake of which is measured by electrical instruments. This is faced above and below with copper plates E (of the same area, 987.22 cm^2) the external surfaces of which assume, under the

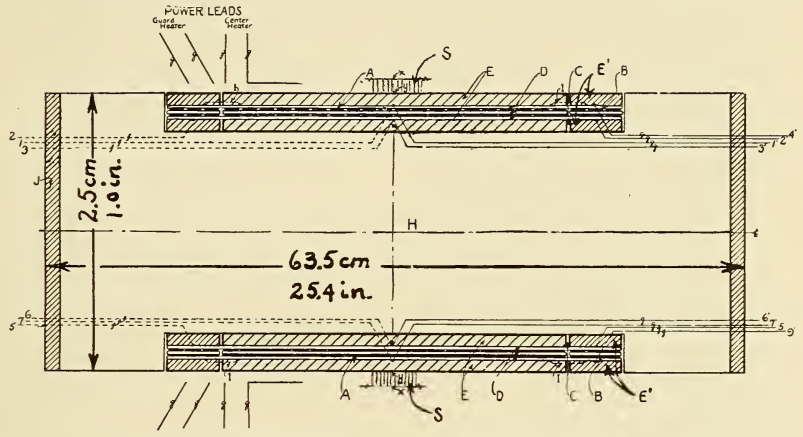

FIG. 1.—*Diagrammatic cross-sectional assembly of heat transmission apparatus. (Thickness magnified 10 times relative to the length.)*

The following itemized description of materials used will illustrate the functional relation of the parts.

A=main center heater } "Advance" resistance ribbon wound on micanite core,
B=guard heater }
C=air (electric and heat insulating space),
D=micanite (electric insulating sheets),
E=copper (heat distributing plates, nickel plated and dull finished) center,
E^1=copper (heat distributing plates, nickel plated and dull finished) guard,
f="constantan" (thermocouple lead wires) 1, 2, 3, etc.,
g=copper (thermocouple and power lead wires) 1′, 2′, 3′, etc.,
H=balsa wood (heat insulator, electric insulator, mount board),
I="constantan" (differential thermocouple wire),
J=steel (frame for reinforcing edges of mount board),
S=textile material (test specimen), extends completely across apparatus,
X=copper constantan (thermocouple used to obtain temperature at top of specimen).

working conditions, a uniform temperature measured by the thermocouple at y. This central heater is surrounded by a coplaner frame B and E' of exactly the same construction, but separately heated and controlled so that E' is maintained at the same temperature as E, indicated by differential thermocouples inserted across the narrow (0.2 cm) air gap C between them. This combination is inserted flush with the upper face of a balsa wood board H (thickness 2.5 cm), which is both a good heat and a good electrical insulator. An exactly similar heating combination inserted in the under face of the same board serves to prevent any escape of

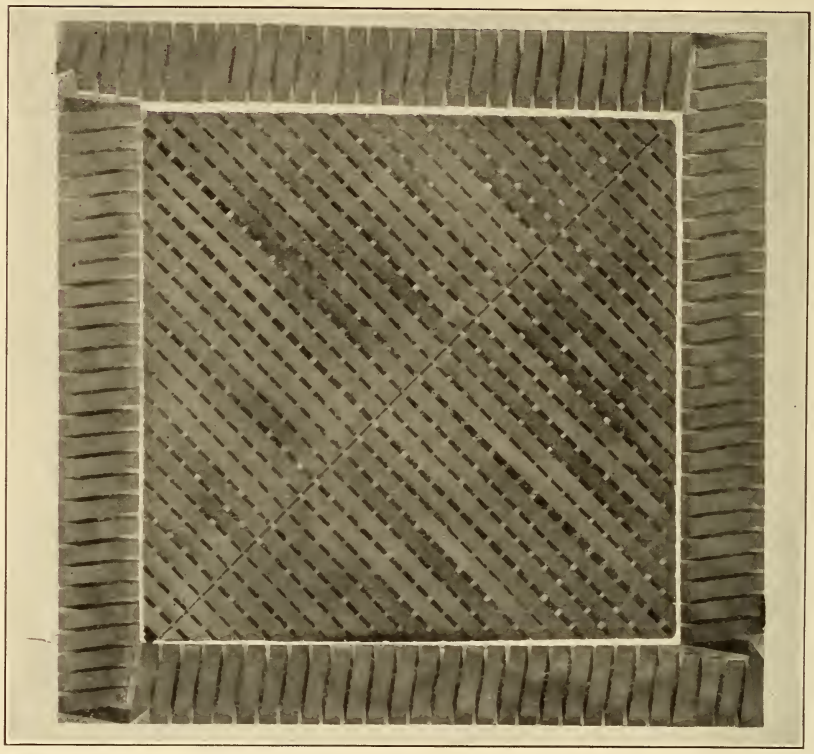

FIG. 2.—*Resistance grids for electrically heating the apparatus*

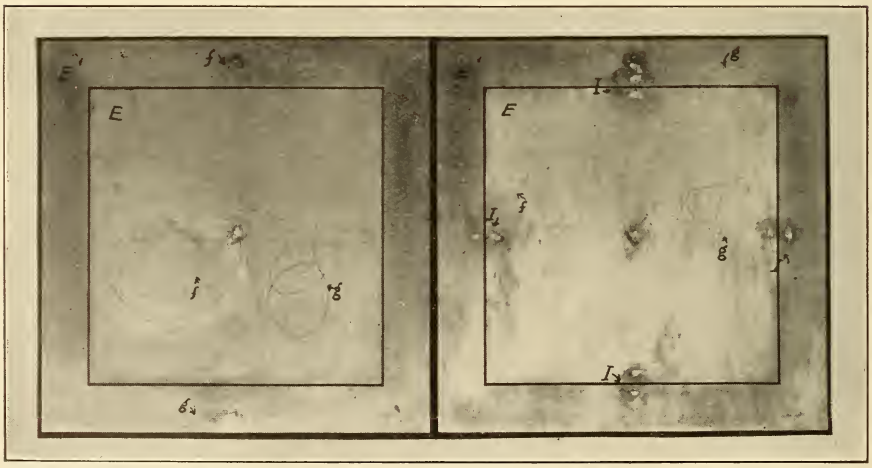

FIG. 3.—*Copper heat distributing plates (center and guard plates separated by air space)*

heat downward from the upper central heater A. It also serves, by inverting the board, for making independent tests. The dimensions are so chosen as to insure that all heat escaping from the mount board comes from the guard ring—none from the central heater. The central heater serves a test area of $(31.42+0.2)^2=1{,}000$ cm^2, where the 0.2 cm is one-half the total air-gap dimension in either direction of the central square.

Figure 4 shows this outfit with test specimen removed from the top. As seen, it can be varied in position from a vertical to a horizontal plane or completely reversed. Rollers provided at three edges serve to tension the test specimen, and four metal strips to press it against the face of the heater after proper tension is applied.

Figure 5 shows the apparatus with test specimen properly mounted, also all accessory equipment used in taking measurements.

The power input to the central heater is computed from the electric current I (measured by a potentiometer method) and the electrical resistance Ω of the grid measured at room temperature, and assumed constant for the working range; an assumption checked as correct by other measurements made under working conditions.

This gives the power input as $I^2\Omega$ watts, and rate of loss of heat per second through the sample

$$H=\frac{I^2\Omega}{4.18} \text{ joules (calories per second)}$$

Substituting in equations (1) and (2) we obtain the thermal resistance

$$R=4.18\frac{\Delta T}{I^2\Omega} \tag{3}$$

and thermal resistivity,

$$r=4.18\frac{\Delta T}{L}\cdot\frac{A}{I^2\Omega}-\frac{R_s}{L} \tag{4}$$

Equation (4) is only applicable if R is found to be a linear function of the thickness as required by (2).

Temperatures were measured by constantan-copper thermocouples using the potentiometer method. ΔT is obtained as the difference in temperature indication of one thermocouple on the face of the hot plate and a second placed opposite this first one in the plane of the outer surface of the fabric at y of Figure 1. The

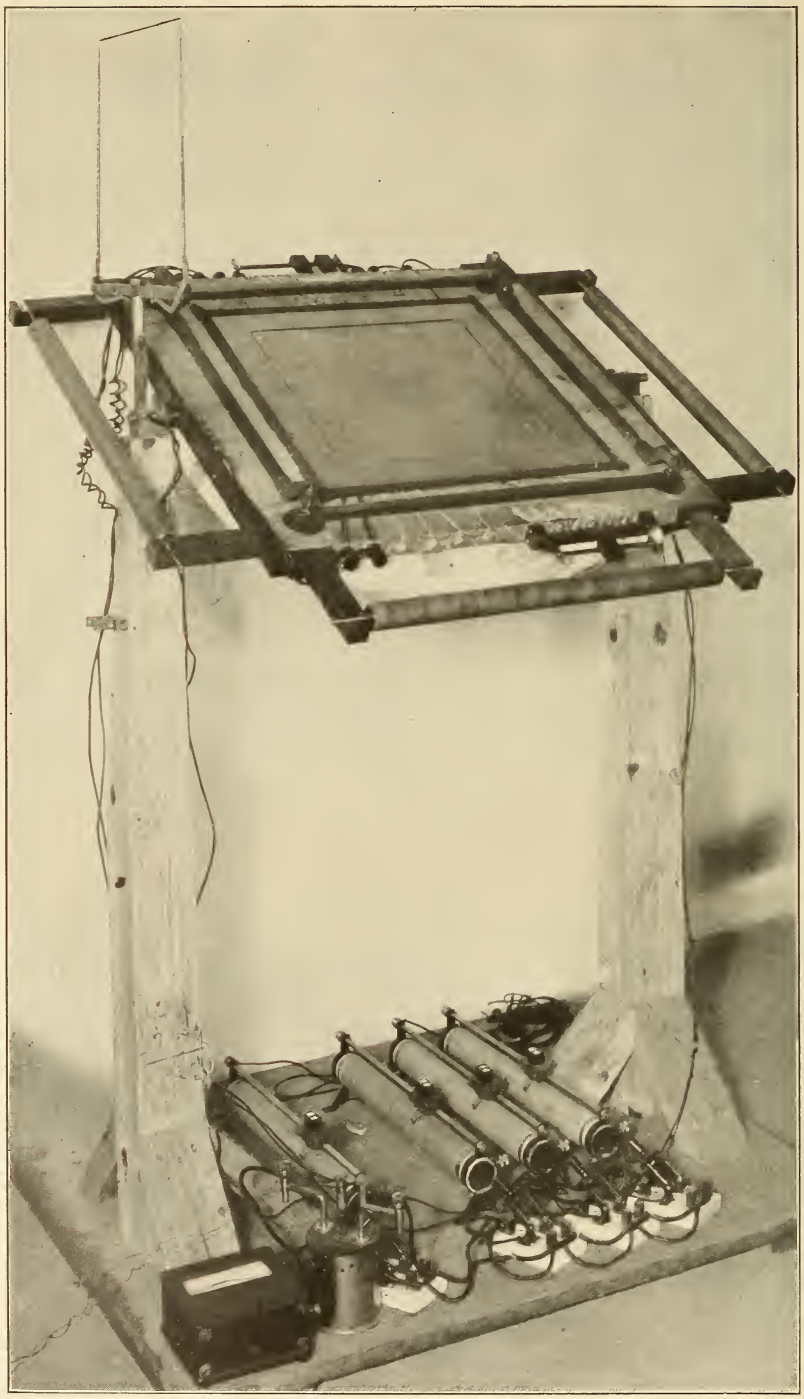

FIG. 4.—*Close range view of heat transmission apparatus*

device for placing the latter is seen as a rectangular loop in Figure 4, the thermocouple being stretched taut between the free ends of the two vertical arms, thus furnishing a physical line which can readily be brought into the plane of the fabric's face.

The thickness L of the fabric was obtained by thrusting a needle of known length perpendicularly through to the plate at the point of location of this thermocouple, and then measuring the length remaining between the thermocouple and free end of the needle. This measurement was corrected by subtracting the thickness of

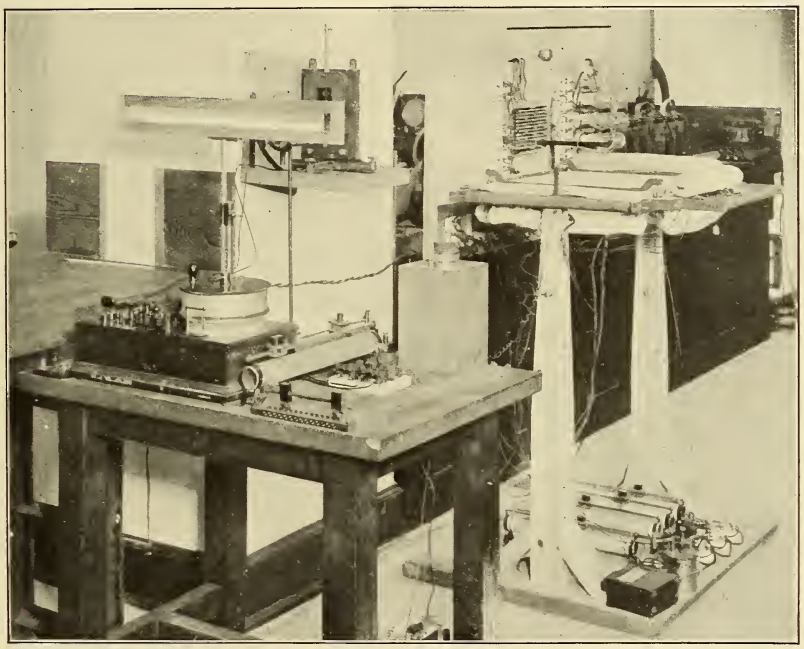

FIG. 5.—*General view of heat transmission apparatus and accessories*

the thermocouple wire, which was 0.02 cm. Very consistent results were obtained.

The procedure in making a test was as follows: The air in the room being maintained at a temperature of 21.1° C. (70° F.) and relative humidity of 65 per cent and the test sample in place, the electric currents in the various heaters were adjusted to maintain the central plate and guard plates at the desired temperature, as indicated in the one case by the thermocouple on the outer face of the central plate and in the other case by zero indications of the differential couples between the central and guard plates. It required about one and one-half hours to reach equilibrium con-

ditions, following which a series of observations of the heating current I, and temperatures furnishing T and ΔT were made. Using equation (3) the thermal resistance R was calculated. Independent tests of the same fabric under the same conditions gave values varying by not more than 1.0 per cent, usually better than this figure. In some cases the value of the thermal resistivity r was also computed using equation (4). Thickness measurements were always taken so that this value could be determined.

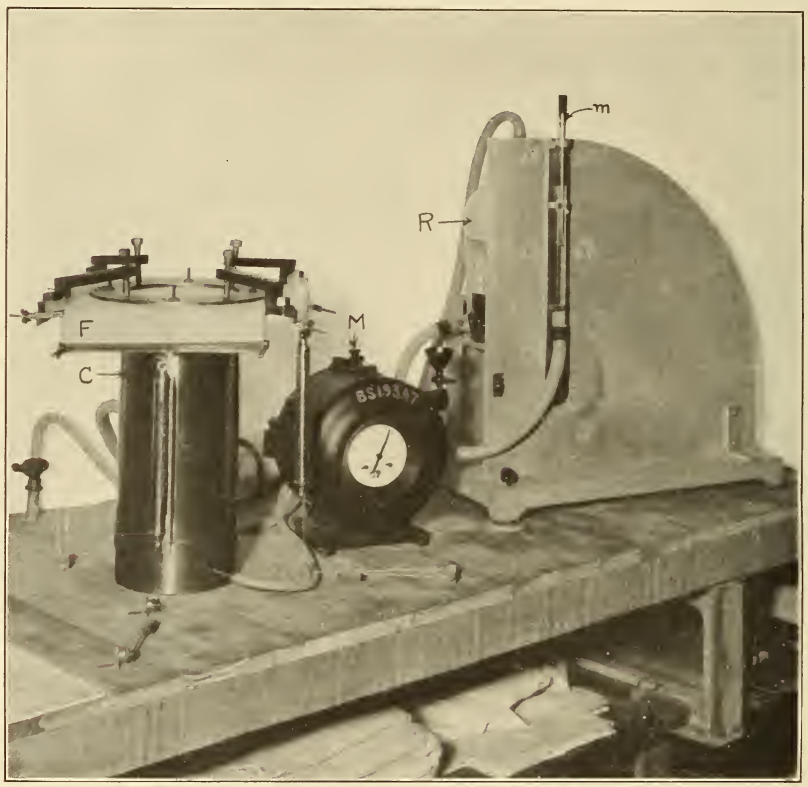

FIG. 6.—*General view of apparatus for determination of permeability to air*

3. APPARATUS FOR DETERMINING PERMEABILITY TO AIR

Figure 6 shows the set-up used for this purpose. Fabric F, under a slight tension, is pressed against the open end of a cylindrical chamber C to form a practically air-tight junction therewith. An aspirator is connected to the outlet of the damp-gas meter M, while the inlet of the meter is connected to the base of the cylindrical chamber C. A pressure take-off located midway on the cylinder wall is connected to the top of the water reservoir

R, while the base of the reservoir is connected to a micrometer manometer.[4]

When the aspirator is turned on it draws air of a determined humidity through the specimen, the cylinder, and the meter in the sequence mentioned. The rate of air flow through the system is determined from time and meter readings. When air is thus drawn through the system there results a lowering of the cylinder pressure, which is indicated by the manometer readings during the test. The difference in the manometer readings before and during air flow is the pressure difference forcing the air through the fabric.

The apparatus measures the quantity of air forced through a definite area (approximately 175 cm^2) of the fabric in a given time under a given pressure difference. It was found that there is a critical pressure difference for each fabric below which the test data must be taken to obtain a constant premeability factor.

To insure consistent results the following precautions were necessary: (1) A definite tension of the fabric was always used—1 per cent of the breaking strength of the fabric in warp and filling directions, respectively; (2) air from the room maintained at 70° F. and at a relative humidity of 65 per cent was drawn through the fabric; (3) eddies in the cylinder were avoided by having the intake cover its entire cross section and a fine wire mesh partition introduced in the cross section just preceding the outlet; (4) vibrations were minimized by mounting the manometer and reservoir on the same rigid base.

The air permeability v was computed by the formula

$$v = \frac{V}{A(P_a - P)t}$$

v being the volume in liters (1,000 cm^3) passing per second through an area of 1,000 cm^2 under a pressure difference of 1 mm of water; V, the total volume passing in t seconds under the observed pressure difference $(P_a - P)$ through the given area A.

Values for v thus obtained from independent tests on the same specimen agreed within 4.0 per cent of the mean value reported for this test.

[4] The reading of the manometer could be improved upon by removing the micrometer and substituting a finely graduated scale with vernier attachment for taking direct mean readings of the height of the water meniscus in the manometer tube. This method of reading would simulate that of the ordinary mercurial barometer.

4. APPARATUS FOR DETERMINING PERMEABILITY TO WATER VAPOR

To devise an adequate test of this property is by no means a simple problem. The presence of absorbed moisture, by swelling the fibers, reduces the permeability to both air and water vapor. In service, the quantity and therefore the effect, of this absorption varies, of course, for any given fabric with the humidity and temperature of the atmosphere and with the rate of perspiration from the body. It is also dependent upon air currents, which vary the rate of evaporation from the fabric. As standard test conditions under which the rate of escape through the fabric is measured, we have chosen saturated water vapor at 37.8° C. (100° F.) on the one side and free air at 21.1° C. (70° F.) and relative humidity 65 per cent on the other. The method of test consists in measuring (by weighing) the rate of escape into the air-conditioned room of water vapor from a glass jar (crystallizing dish) covered with one layer of fabric, the water in the jar being maintained at the desired temperature by a surrounding water bath.

Figure 7 shows the apparatus, which is arranged to test 10 samples in the same run, 4 being shown in position. The glass jars are inserted in the water bath, which is maintained at temperature by an immersed electric-heating strip and stirred by a motor-driven double propeller. The tank is covered top, bottom, and sides with asbestos to the effect that, under the plan of operation, occasional attention in regulating the heater currents is sufficient to maintain the temperature within a range of $\pm 2°$ F. during a day's run.

To carry out a test, the sample, which in the present investigation was confined to blankets, is fastened with rubber cement securely over the mouth (of known area approximately 75 cm^2) of the test jar partially filled with the requisite amount of water. In this case no definite tension is used on the specimen, simply because of the difficulties involved. The water bath is brought up to temperature (at a rate of 2° in three minutes) by a clamp-on electric heater, then maintained by the immersed heating strip. The 10 jars covered with the test samples are brought into place, while an eleventh uncovered jar, containing an equal amount of water, serves, by its rate of evaporation, merely for control purposes in different runs. The evaporation is determined by removing at measured intervals a jar and weighing, then replacing it for continued evaporation. This weighing requires about three

minutes, so that while it is being done the bath temperature is conserved by inserting in place of the test jar another open one partially filled and at the same temperature.

During a day's run a number of observations on each sample are made. When the evaporation divided by the time interval

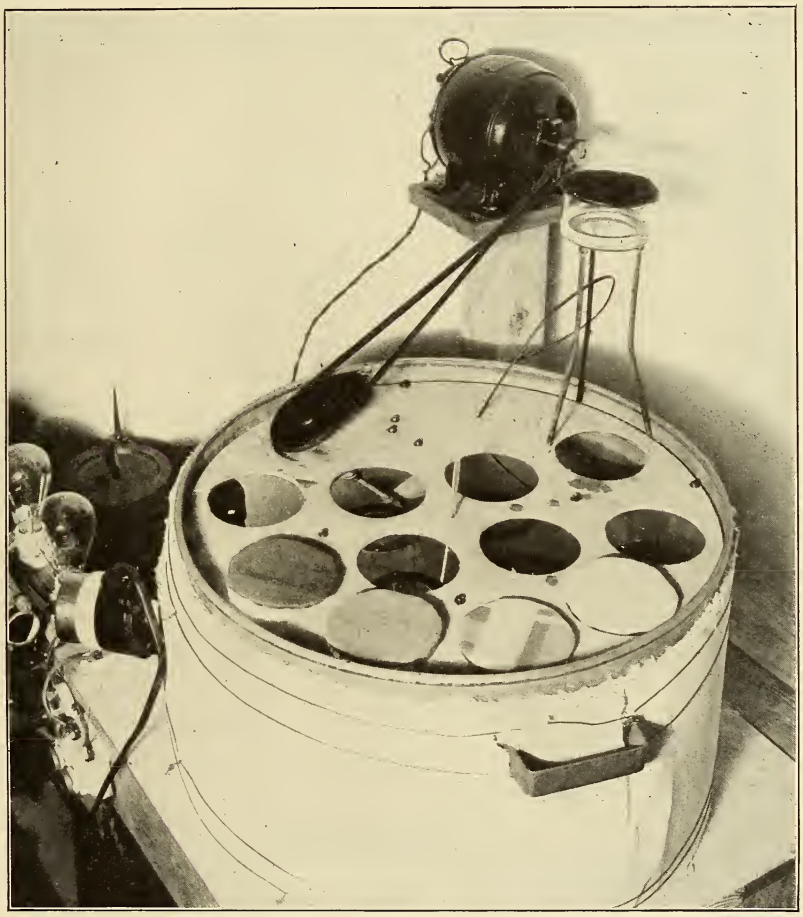

FIG. 7.—*Apparatus for determination of permeability to water vapor*

between weighings becomes constant—that is, to within ± 5 per cent, which occurs generally after two to three hours' run—this rate of evaporation is taken as the constant for the specimens. It was found that the most consistent results were obtained by using the average of two runs, the second test being made with the surfaces of the specimen reversed. This method possibly takes into account the effect of any difference in the two surfaces which would naturally affect the evaporation therefrom.

III. EXPERIMENTAL RESULTS

In Table 1 are incorporated illustrative test data on a number of samples taken from new blankets selected as typical of the variety to be obtained in the trade. They varied in material, thickness, weight, and manufacture.

It will be observed that the data in the table have been recorded in both English and metric units and conversion factors are given. The discussion, in general, is in metric units, but, where considered helpful to those not familiar with the metric, the English equivalents are also given.

The terms used in the table are defined as follows:

Thermal resistance.—An index of the heat-insulating value (R). It is defined in metric units as follows: The number of °C. (degrees centigrade) temperature difference between the two surfaces of a fabric, required to produce a heat flow of 1 calorie per second through 1,000 cm^2 test area of specimen. Strictly speaking, this value should be called the "apparent" thermal resistance.

Permeability to air.—The number of liters of air which will flow through a specimen 1,000 cm^2 in area in one second, for unit pressure difference (1 mm of water) under the standard conditions of this test.

Permeability to water vapor.—The number of milligrams of water vapor which will flow through a specimen 1,000 cm^2 area per second, when the water supply beneath the specimen is maintained at 38° C. (100° F.) and the air surrounding the outside of the specimen is maintained at 65 per cent relative humidity at a temperature of 21.1° C. (70.0° F.).

The remaining terms used in the table are generally understood, so will not be defined further.

The thermal-resistance measurements were made with the hot plate at an average temperature of 53.3° C. (128.0° F.), the outside or surrounding still air at 21.1° C. (70.0° F.) and its relative humidity 62.5 per cent. The tests of weight, permeability to air, and water vapor were also made with the specimens exposed to normal conditioned air.

The data are listed in column A of the table in the order of increasing thermal resistance, which varies from 3.0 to 8.6 units. The hot-plate temperature of the run and the per cent relative humidity of the surrounding atmosphere are recorded in columns B and C, respectively. Column D contains values of thermal resistance computed by an equation to be discussed later. Thick-

ness, weight, density, as also permeability to air and water vapor, are likewise incorporated therein as part of the information associated with the thermal properties. (See columns E to I.)

An inspection of the data for existence of possible relations between thermal resistance and the several tests reveals no simple correlations except in the case of "thermal resistance" and "thickness" which have been plotted in Figure 8.

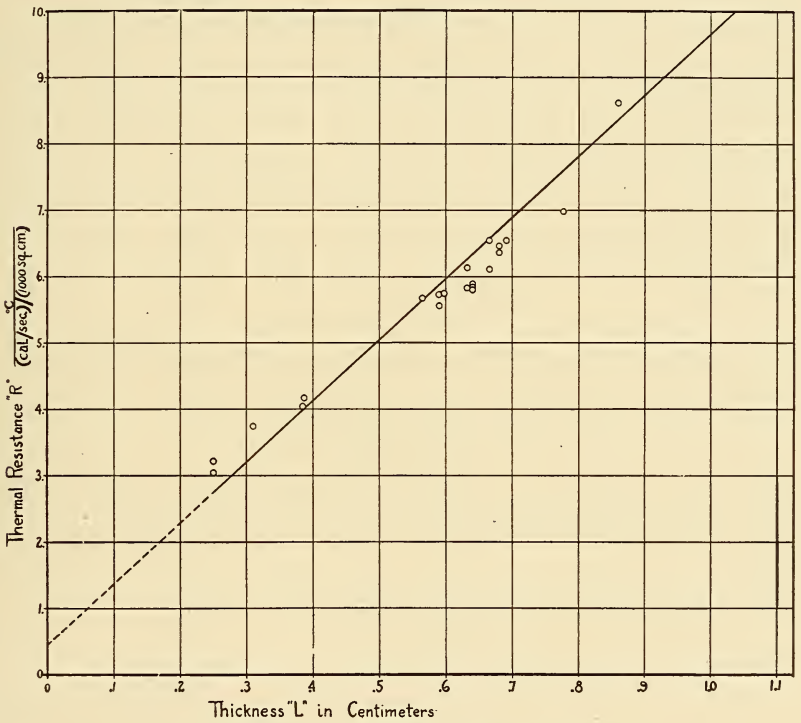

FIG. 8.—*Thermal resistance v. thickness (blankets)*

(Reference Table 1)

The natural line, best satisfying the illustrative data only, would appear to give a larger intercept and less slope than the line drawn in Figure 8. This line, however, was determined from data presented here, together with other data on typical blankets not included in this paper, which it is planned to give in a subsequent publication. In the plot we find a surprising grouping of the plotted points about a straight line cutting the vertical axis at $R = 0.46$. The scattering from the line is, however, much larger than errors of measurement or variations between samples

from the same blanket. It may be noted that the deviation of the points from the drawn line are within equal plus and minus limits. This observation holds also for all blankets tested to date, which when plotted extend the line in Figure 8 to twice the magnitude shown here without altering the plus and minus deviation range. It is beyond the scope of this paper to deal further with this correlation, but it will be discussed in greater detail in another paper.

Thorough analysis of all blankets tested to date results in a convenient correlation of thermal resistance, weight, and density. The development of the equations will not be discussed until a later date; however, they have been used to compute the thermal resistance corrected for a uniform temperature of hot plate (51.7° C.). These values are recorded in column D of the table. The two equations are given below for reference. They are as follows:

$$R = \frac{0.00643\ W}{d + 0\ .0206} + R_s$$

which is found to apply for typical blanket constructions having densities in the range 0.0206 to 0.0835 g/cm ^{3} and

$$R = \frac{0.01286\ W}{d - 0.0422} + R_s$$

which also is found to apply for typical blanket constructions having densities in the range 0.0835 to at least 0.23 gm/cm^3

where

R = Thermal resistance for 1,000 cm^2.

W = Weight in g/1,000 cm^2.

d = Density in g/cm^3.

R_s = A constant (0.46), which apparently is an average surface thermal resistance for all blankets tested to date.

They hold for the proposed standard test conditions, and apply particularly for hot plate temperature of 51.7° C. (125° F.)

Consistent agreement is shown between the calculated value of thermal resistance corrected for uniform temperature of hot plate (51.7° C. or 125° F.), and the value of the experimental points which were not always run at the same temperature. (Refer to columns A, B, and D of the table.)

Referring again to the plot in Figure 8, it might be well to point out here that the thermal resistance for a given thickness may vary plus or minus from the average line, but in conformity, however, with the two equations given above. Since there are no thickness terms appearing in these equations, each is applicable for any assumed thickness and weight within the respective ranges

TABLE 1.—Typical Test Data on Blankets (English and Metric Units)

Test	A Thermal resistance, R.		B Temperature of hot plate, T.		C	D (R)—Computed for T=51.7°C. or T=125°F. R_T[1]		E Thickness, L.		F Weight, W.		G Density, d.		H Permeability to— Air, v.		I Permeability to— Water vapor, l.	
Dimension of unit of measurement	Degrees Fahrenheit ÷ (Btu./hr.)/ft.^{2}	Degrees centigrade ÷ (cal./sec.)/1,000 cm^2	Degrees Fahrenheit	Degrees centigrade.	Relative humidity (per cent).	Degrees Fahrenheit ÷ (Btu./hr.)/ft.^{2}	Degrees centigrade ÷ (cal./sec.)/1,000 cm^2	Inches.	Centimeters.	Ounces/yd.^{2}	Grams/1,000 cm^2	Ounces/in.^{3}	Grams/cm^3	(In.^{3}/sec.)/in.^{2} per 0.1 inch water pressure.	(Liters/sec.)/1,000 cm^2 per mm water pressure.	(Grains/min)/ft.^{2}	(Mg/sec.)/1,000 cm^2
Conversion factor	[2]0.1357		[2](°C.×1.8)+32=°F			[2]0.1357		[2]0.394		[2]0.295		[2]0.578		[2]2.68×10—^{6}		[2]0.995	
Specimen																	
1	0.414	3.05	124.5	51.3	66.0	0.414	3.05	0.099	0.25	12.7	43.2	0.0999	0.1728	1.377	0.00514	4.40	4.42
2	.441	3.25	125.6	51.9	67.0	.426	3.14	.099	.25	15.4	52.1	.1205	.2084	.632	.00236	4.43	4.45
3	.509	3.75	125.0	51.7	65.0	.509	3.75	.122	.31	18.2	61.8	.1152	.1993	1.260	.00470	4.43	4.45
4	.550	4.05	126.5	52.4	64.0	.563	4.15	.151	.38[4]	14.1	47.8	.0721	.1247	4.181	.01560	4.08	4.10
5	.566	4.17	125.6	51.9	61.0	.522	3.85	.152	.38[7]	8.9	30.1[5]	.0450	.0779	10.827	.04040	4.12	4.14
6	.763	5.62	130.7	54.7	62.0	.820	6.04	.232	.58[9]	11.2	37.8[5]	.0372	.0643	3.345	.01248	3.86	3.88
6′	.778	5.73	124.0	51.0	70.0	.820	6.04	.232	.58[9]	11.2	37.8[5]	.0372	.0643	3.345	.01248	3.86	3.88
7	.771	5.68	130.6	54.6	56.0	.799	5.89	.222	.56[4]	10.4	35.2	.0360	.0624	3.806	.01420	3.84	3.86
8	.780	5.75	129.5	54.0	62.0	.842	6.21	.235	.59[7]	10.1	37.0	.0358	.0620	2.701	.01008	3.72	3.74
9	.788	5.81	130.6	54.6	54.0	.817	6.02	.252	.64	16.5	55.9	.0505	.0873	1.447	.00540	3.66	3.68
10	.791	5.83	128.5	53.4	61.0	.837	6.17	.249	.63[2]	13.3	45.1	.0413	.0714	2.251	.00840	3.72	3.74
10′	.833	6.14	126.0	52.1	62.5	.837	6.17	.249	.63[2]	13.3	45.1	.0413	.0714	2.251	.00840	3.72	3.74
11	.794	5.85	130.5	54.5	61.0	.832	6.13	.252	.64	14.2	48.3	.0436	.0755	5.199	.01940	3.74	3.76
12	.801	5.90	130.5	54.5	61.0	.833	6.14	.252	.64	14.4	48.8	.0439	.0759	2.332	.00870	3.76	3.78
13	.830	6.12	128.2	53.3	61.0	.893	6.58	.262	.66[5]	13.5	45.6	.0397	.0686	1.699	.00634	3.64	3.66
14	.864	6.37	127.0	52.6	65.0	.879	6.48	.268	.68	15.1	51.2	.0435	.0753	1.528	.00570	3.59	3.61
14′	.878	6.47	128.9	53.7	68.0	.879	6.48	.268	.68	15.1	51.2	.0435	.0753	1.528	.00570	3.59	3.61
15	.889	6.55	124.6	51.2	65.0	.938	6.91	.272	.69[1]	13.5	45.9	.0384	.0664	2.594	.00968	3.62	3.64
16	.889	6.55	124.6	51.2	61.0	.838	6.28	.262	.66[5]	15.3	51.8	.0450	.0779	1.619	.00604	3.81	3.83
17	.947	6.98	126.9	52.6	64.0	.958	7.06	.303	.77	18.8	63.7	.0478	.0827	3.645	.01360	3.41	3.43
18	1.170	8.62	127.5	53.0	64.5	1.190	8.78	.339	.86	15.7	53.0[7]	.0357	.0617	7.879	.02940	3.23	3.25

[1] R_T=Computed value of R for a temperature T.
[2] To convert metric units to English units multiply the metric unit by the factor given or obtain as indicated in the case of temperature.

of density. If we assume zero thickness, the weight and density would also be zero, and each equation would give the same intercept or average surface resistance, viz, $R = R_S = 0.46$. If we assume any value of density within the ranges prescribed for the two equations the value $(R - R_S)$ is directly proportional to weight. Therefore, for a given density the line correlating thermal resistance (R) and weight (W) is a line intersecting the R axis at $R = 0.46$ and having a constant slope.

IV. DISCUSSION

The method developed for measuring the thermal resistance of blankets gives closely reproducible results on the same specimens and is found to give very consistent results on different specimens from the same blanket.

The requirement that the test be made in conditioned air is most practical, for service atmospheric conditions can be readily duplicated in the test. Another provision specifies the hot-plate temperature to be 51.7° C. (125.0° F.) and room temperature to be 21.1° C. (70° F.). This latter provision is made to duplicate in the test other service conditions, explained as follows: One is concerned with the use of blankets in relatively cold weather when the temperature in a bedroom with windows open is a little above freezing. This temperature has been assumed to be about 7.2° C. (45° F.) Normal "bloodheat" of a person's body is about 37.8° C. (100° F.). The temperature difference which should be duplicated in our test, then, is $(37.8 - 7.2 = 30.6°$ C.) or $(100 - 45 = 55.0°$ F.). Therefore, by heating the hot plate beneath the test specimen to 51.7° C. (125° F.) and allowing the top surface of specimen to be exposed to conditioned air at 21.1° C. (70° F.), we may thereby duplicate the general service conditions as shown above as follows: $(51.7 - 21.1 = 30.6°$ C.) or $(125 - 70 = 55°$ F.).

In conclusion, it is believed that the test conditions prescribed here duplicate service conditions sufficiently for the thermal-resistance measurement to be used as an index of the heat insulating value of blankets in use under normal service conditions.

It is planned in a later publication to give justification for the correlations of thermal resistance with thickness, weight, and density, so that blankets may be designed or constructed to give a predetermined heat insulation.

It is also planned to supplement this paper immediately with a publication giving specifications for constructing and operating the heat transmission apparatus here described.

WASHINGTON, May 16, 1924.